BIOPETROLOGY

Article

Foraminiferans from the Late Devonian Frasnian-Famennian (F-F) boundary section at Zhongnan, Guilin, Guangxi , China

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Abstract

Foraminifera fossils, including 13 genus, 19 species (8 undetermined species), are described from the Frasnian-Famennian (F-F) boundary section at Zhongnancun of Guilin. The single-chambered foraminiferans include ten species: *Cribrosphaeroides parasimplex*, *C. robusta*, *Archaesphaera giganta*, *A. crassa*, *Parathurammina horrida*, *P.* sp., *Paracaligella antropovi*, *P.* sp., *Bisphaera* sp., *Irregularina* sp. The dual-chambered foraminiferans include *Eovolutina elementa* and *Earlandia* sp. The multiple chambered foraminiferans include 7 species, such as *Nanicella* sp., *Septabrunsiina donica*, *Paratikhinella cannula*, *Tikhinella measpis*, *T.* sp., *Nodosinella* cf. *evlanensis*, and *N.* sp. The foraminiferans can be classified into four assemblages: the first assemblage dominated by the elements of Parathuramminidae; the second dominated by the elements of Nodosinellidae; the third dominated by the elements of Parathuramminidae and Caligellidae, and the fourth dominated by the elements of Parathuramminidae. The extinction rate of foraminiferans in this section across the F-F event horizon is 7-12%, while the extinction rate below the F-F event horizon is 22%, indicating that the F-F event did not cause a mass extinction in the foraminiferans.

Key words: Foraminiferans, Late Devonian, Frasnian-Famennian event, mass extinction, Guilin.

Funding This study was supported by the key Program of the National Natural Science Foundation of China through grant 42330203 to Dai-Zhao Chen.

Cite it as: Wu, et al. 2026. Foraminiferans from the Late Devonian Frasnian-Famennian (F-F) boundary section at Zhongnancun of Guilin, Guangxi province, South China. Biopetrology, 6(1): 1-33. http://biopetrology.com/fftldf

1 Introduction

The F-F event which occurred at the transition of the Frasnian and the Famennian (referred to as F-F) stage during the Late Devonian is a significant global evolutionary event, referring to the mass extinction of numerous species of benthic animals, especially reef-building organisms such as coral and stromatoporoid (Sepkoski, 1982; Buggisch, 1991; Walliser, 1996; Liao, 2001; Racki, 2005; Blieck, 2007).

Many scholars have studied the F-F event in brachiopods, corals, stromatoporoids and bryozoans, but if it existed in foraminiferans has not been discussed to date. Many scholars have conducted systematic paleontological studies on the foraminifera fossils from the Devonian Period in China. However, no scholar has discussed the extinction pattern of the foraminifera during the F-F event period.

Foraminiferans are one of the important groups of shallow-sea benthic animals in the Late Devonian, characterized by calcareous shells consisting of one or more than one chamber (Hao et al., 1982; Ji, 1985; Fu, 1985; Zhang, 1986; Wang, 1987; Lin et al., 1989, 1990; Tang, 2023). Foreign scholars have described at least 200 species of foraminifera fossils from the Late Devonian, which is a good foundation for studying the foraminiferans in the F-F event horizon.

In this paper a detailed systematic paleontological study of the foraminiferans in the Upper Devonian at Zhongnan village, Guilin, Guangxi province, South China. The fossils were identified and divided into assemblages, and heir abundances calculated. The change in the species composition and abundance of the foraminiferans in the F-F event horizon was analyzed.

2 Geologic Settings

Since the Proterozoic, the Guilin region has undergone a series of tectonic events, including the Caledonian movement, Hercynian–Indosinian movement, Yanshanian movement and Himalayan orogenies. The Devonian system in this area well developed, and carbonate rocks of the Middle and the Late Devonian formed a shallow-sea carbonate platform that was nearly 40 km in width from east to west and nearly 80 km in length from north to south (Shen et al., 1994). The lithofacies palaeogeography was influenced by the Caledonian movement. The overall palaeogeographic pattern of the Devonian was a southward-deepening ocean basin. From the Lower to the Upper Devonian, the deposits gradually changed from a dominance of terrigenous clastic rocks to a dominance of carbonate rocks. Overall, it was a set of sedimentary sequences under the background of marine transgression, and with the control of syn-sedimentary faulting activities led to the distribution of alternating shallow-water carbonate platforms and deep-water basins starting from the late Early Devonian period (Fig. 1) (Qin et al., 2000). The evolution of the Devonian sedimentary facies in the Guilin area can be roughly divided into three stages. During the first stage (Early Devonian and Early Middle Devonian), differential movement along the basement fault was weak, the crust was relatively stable, and sedimentary differentiation was not obvious, represented terrigenous clastic sedimentation in a coastal environment. In the second stage (late Middle Devonian), the differential movement of the basement fault increased, and sedimentary differentiation was distinct, causing the formation of the carbonate platform carbonates and basin deposits. In the third stage (Late Devonian), the differential movement of the basement fault was intense, and sedimentary differentiation was very distinct and complex, resulted in a palaeogeographic setting of fault-controlled platforms and fault-controlled troughs (Fang, 1985, 1986).

The section studied here is located at Zhongnan village (Fig. 1), Yangshuo county, Guilin city. The late Devonian strata in this include the Gubi Formation and the Rongxian Formation. The Gubi Formation is mainly composed of breccia limestone, oncolite limestone, and calcarenitic turbidite,

with brachiopods. The Rongxian Formation is mainly composed of light gray and gray-white bioclastic limestone and oolitic limestone, with brachiopods, corals, algae, and other fossils (Zhong et al., 1992; Yin, 1997).

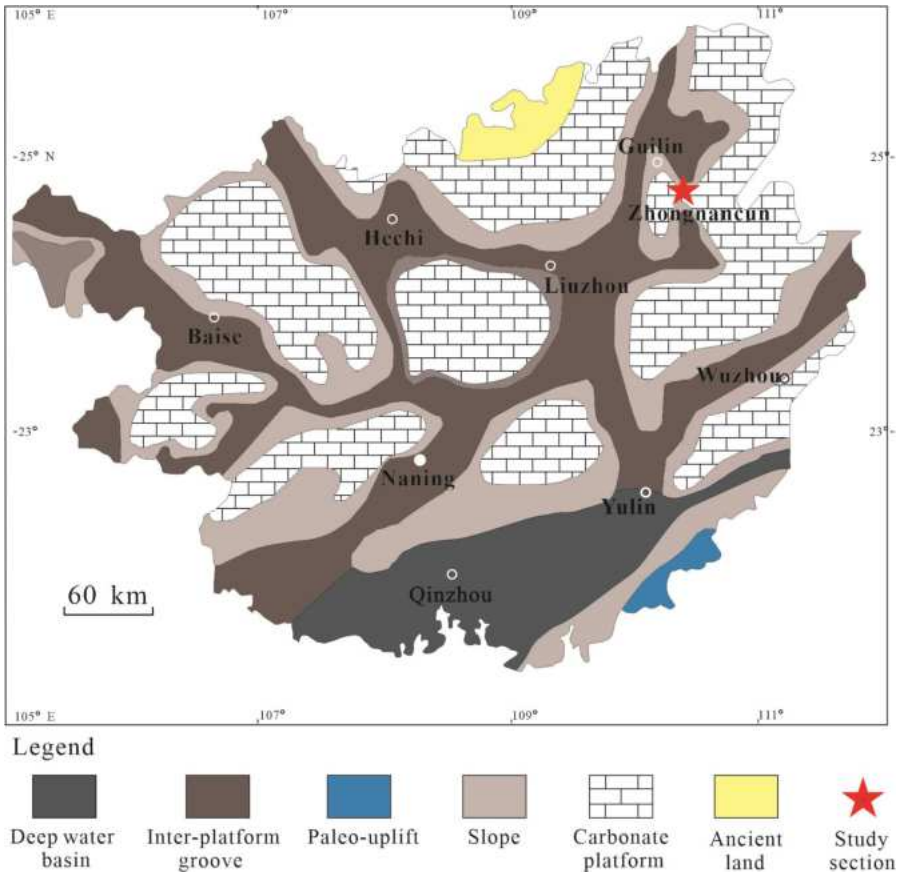

Fig. 1 Lithofacies paleogeography of the Devonian in Guangxi (Modified from Zhang et al. 2019)

3 Materials and Methods

The Frasnian and Famenian intervals in Zhongnan section are146 meters thick, and was divided into 63 layers based on lithology. In this paper, the foraminifera fossils, lithology and sedimentary environments of layers 24 to 63. A total of 88 samples were collected, and 118 fossil and rock thin sections (50×70 mm) were made. The Leica biological microscope was used for observation and photography. The foraminifera fossils were observed, analyzed, and identified to species. Their abundance was counted, and the composition and abundance of species and their changes across the F-F event horizon were analyzed.

4 Foraminiferans and Associated Fossils in the F-F boundary section at Zhongnan

The foraminiferans identified from the Zhongnan section include 19 species belonging to 13 genera. They are as follows:

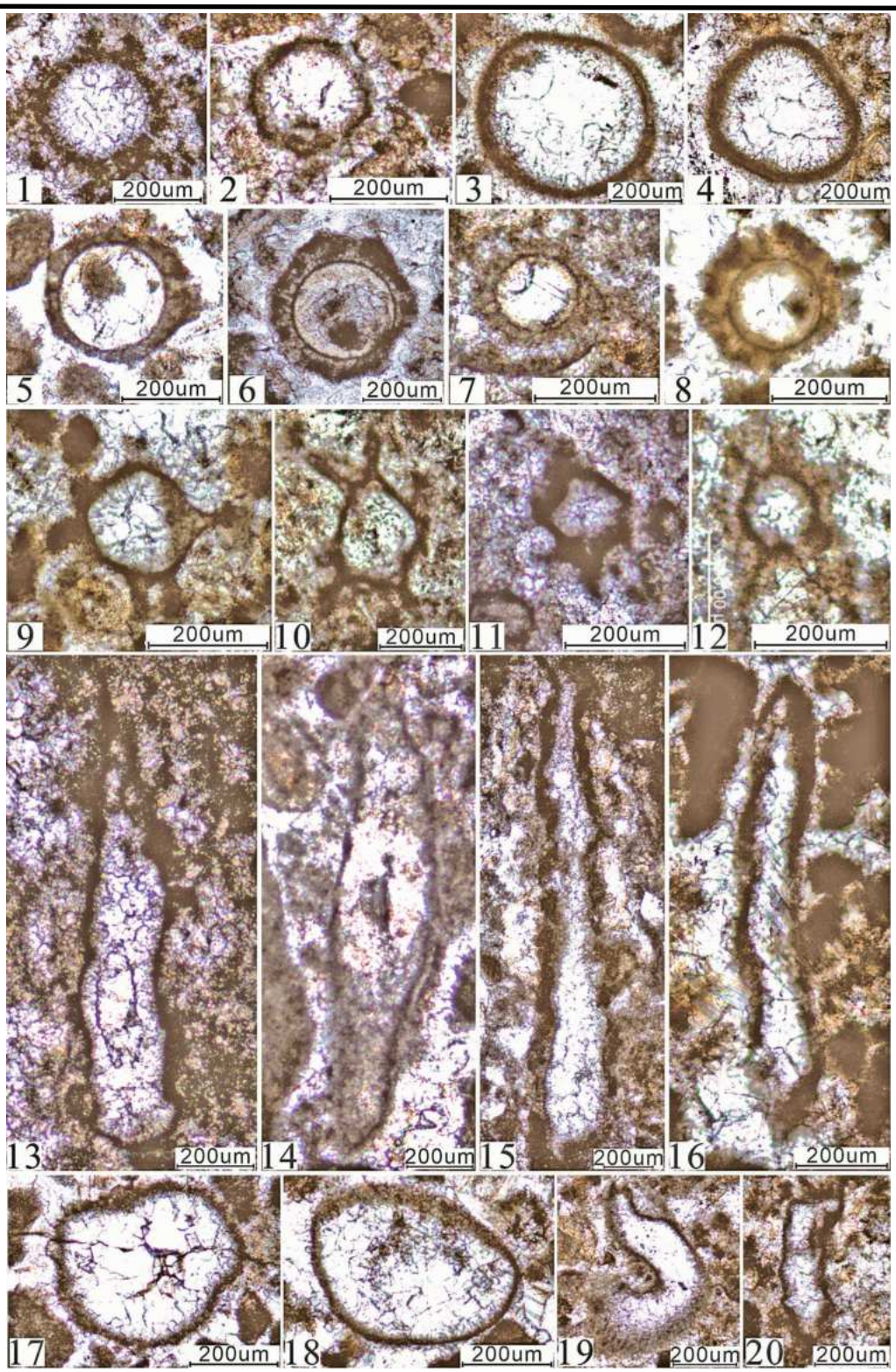

Fig. 2 Foraminiferans in the F-F boundary section of Zhongnan, Guilin, Guangxi province, China.

1, 2. *Cribrosphaeroides parasimplex*, 28th layer; 3, 4. *Cribrosphaeroides* (*Parphia*) *robusta*, 1965, 28th layer, 33th layer; 5,6. *Archaesphaera giganta*, 30th layer, 28th layer; 7, 8. *Archaesphaera crassa*, 44th layer, 33-34layers; 9, 10. *Parathurammina horrida*, 1965, 28th layer; 11, 12. *Parathurammina* sp., 54th layer, 26th layer; 13, 14. *Paracaligella antropovi*, 44th layer, 54th layer; 15, 16. *Paracaligella* sp., 46th layer, 30th layer; 17, 18. *Bisphaera* sp., 33th layer, 38th layer; 19, 20. *Irregularina* sp., 28th layer, 31th layer.

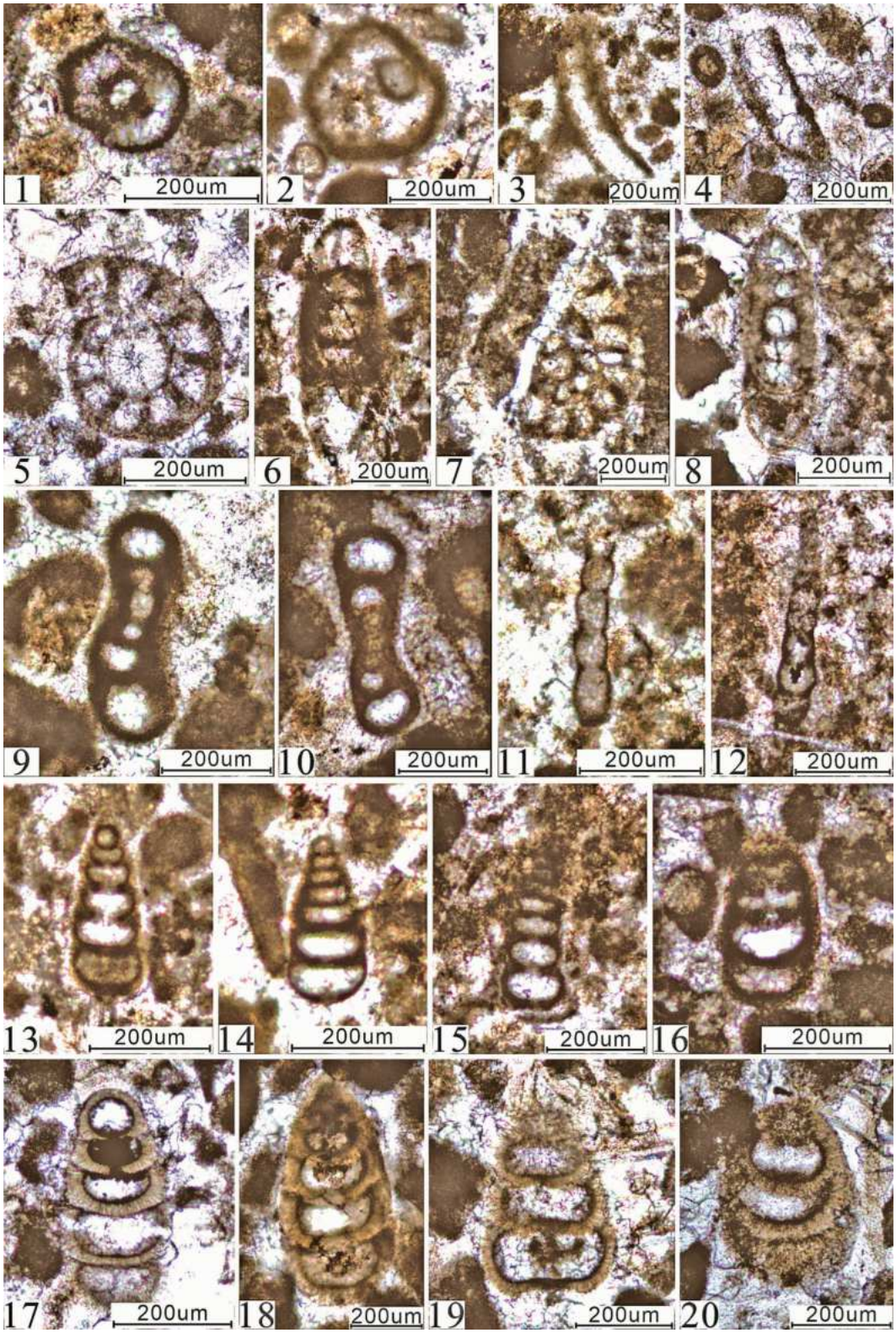

Fig. 3 Foraminiferans in the F-F boundary section of Zhongnan, Guilin, Guangxi, province, China.

1, 2. *Eovolutina elementa* , 31st layer, 43rd layer; 3, 4. *Earlandia* sp., 24th layer, 37th layer; 5-8. *Nanicella* sp., 30th layer, 28th layer, 44th layer, 34th layer; 9, 10. *Septabrunsiina* cf. *donica*, 28th layer; 11, 12. *Paratikhinella cannula*, 31st layer; 13, 14. *Tikhinella* cf. *measpis*, 28th layer, 31st layer;; 15, 16. *Tikhinella* sp., 31st layer; 17, 18. *Nodosinella* cf. *evlanensis*, 30th layer, 32nd layer; 19, 20. *Nodosinella* sp., 30th layer.

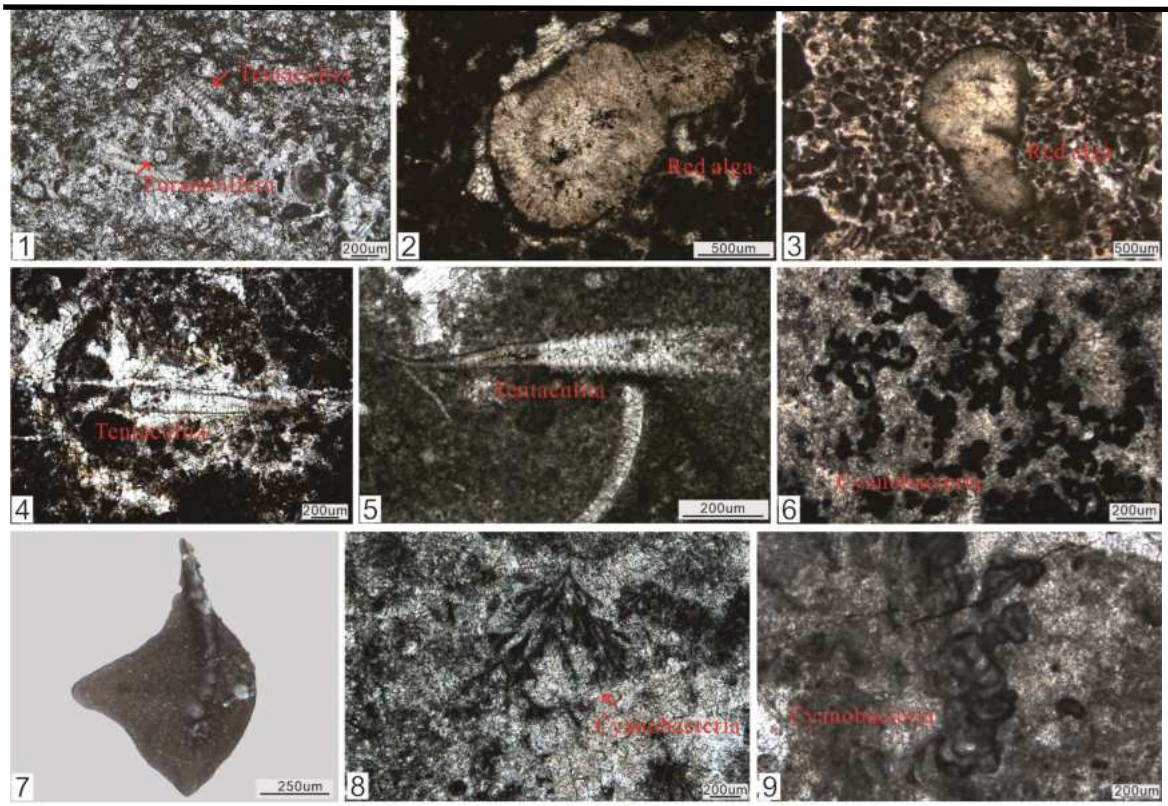

Fig. 4 Photomicrographs of fossils associated with foraminiferans in the Devonian F-F boundary section at Zhongnan village, Guilin, Guangxi province, China.

1, 4, 5. Tentaculites, 31th layer, 51th layer, 55th layer; 2. red algae, 34th layer; 3. red algae, 44th layer; 6. *Izhella*, 55th layer; 7. *Palmatolepis subperlobata*, 56th layer; 8. *Paraepiphyton*, 59th layer; 9. *Renalcis*, 61th layer.

Layers 24-27: with fossil fragments of foraminiferans, brachiopods, stromatolites, ostracods, red algae, corals, cyanobacteria, etc.

There are 11 species of foraminiferans: *Cribrosphaeroides parasimplex (*Fig.2-1, 2-2), *Archaesphaera giganta (*Fig.2-5, 2-6), *Archaesphaera crassa (*Fig.2-7, 2-8), *Parathurammina horrida (*Fig.2-9, 2-10), *Parathurammina* sp. (Fig.2-11, 2-12), *Paracaligella antropovi (*Fig.2-13, 2-14), *Paracaligella* sp. (Fig.2-15, 2-16), *Irregularina* sp. (Fig.2-19, 2-20), *Eovolutina elementa (*Fig.3-1, 3-2), *Earlandia* sp. (Fig.3-3, 3-4), *Nanicella* sp. (Fig.3-5, 3-6, 3-7, 3-8).

Layers 28-34: rich in foraminifera fossils, associated with Tentaculites (Fig. 4-1), stromatoporoids, rugose corals, ostracods, cyanobacteria, red algae (Fig, 4-2), brachiopods, etc.

Genera and spices of foraminiferans are abundant. 19 species appeared in this layer. *Septabrunsiina donica (*Fig. 3-9, 3-10) only appeared in the 28th layer. *Paratikhinella cannula (*Fig. 3-11, 3-12) appeared in the 28th to 31st layers. *Tikhinella measpis (*Fig. 3-13, 3-14) appeared in the 28th to 34th layers. The larger-shelled *Bisphaera* sp. (Fig. 2-17, 2-18) began to appear in the 31st layer.

Layer 35-44: with a great number of foraminiferans, rich Tentaculites fossils in the thin-bedded limestone, as well as large brachiopods, stromatoporoids, corals, cyanobacteria, red algae (Fig. 4-3), ostracods, and gastropods.

16 species of foraminiferans identified, *Nodosinella* cf. *Evlanensis (*Fig. 3-17, 3-18) only continues to the 38th layer, *Nodosinella* sp. (Fig. 3-19, 3-20) only continues to the 40th layer.

Layer 45-51: with foraminiferans, brachiopods, crinoids, stromatoporoids (Figure 4-4), ostracods, cyanobacteria, etc.

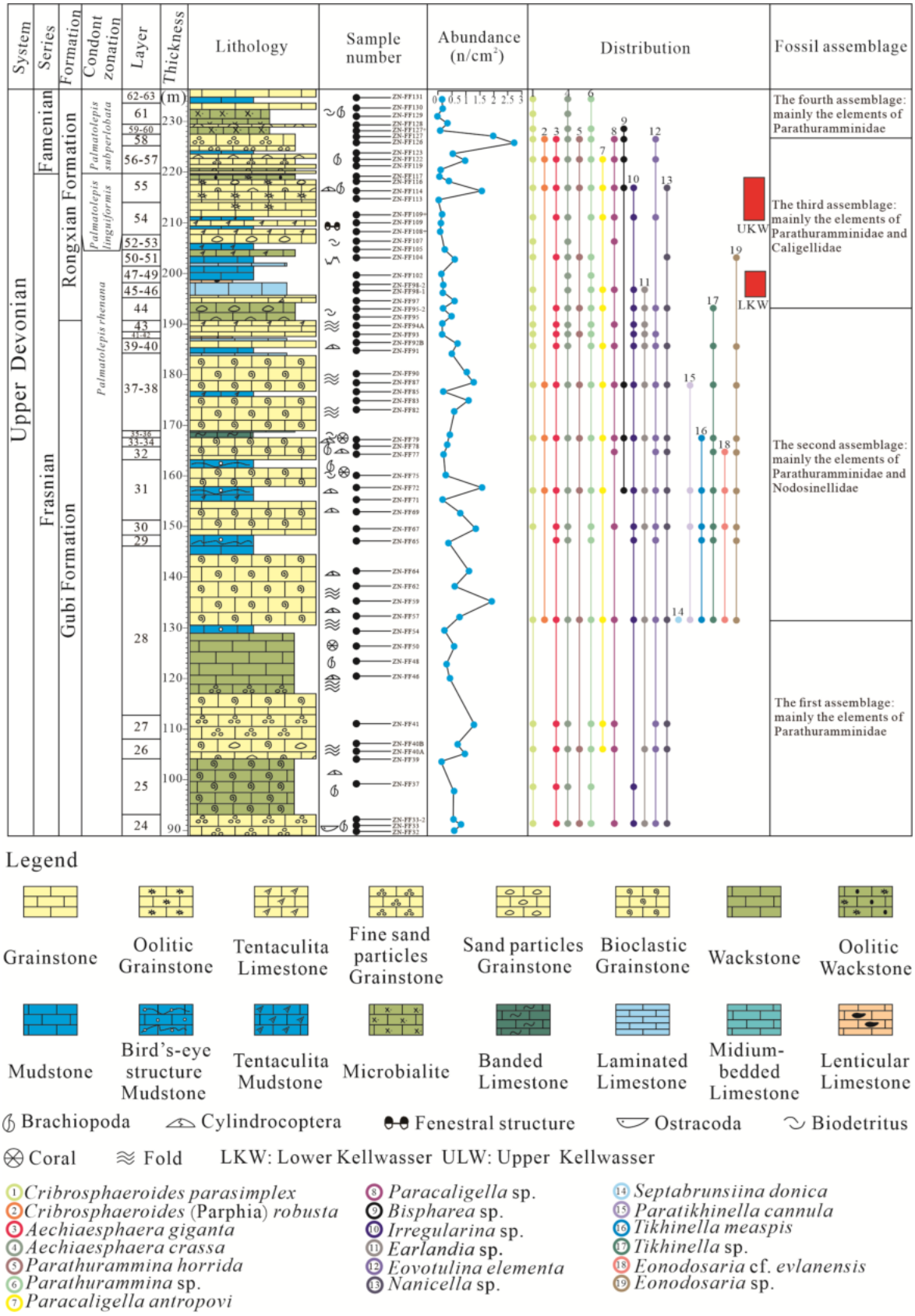

Fig. 5 Comprehensive column of the F-F boundary section at Zhongnan village, Guilin, Guangxi province, China.

Layer 52-55: with foraminiferans, brachiopods, stromatolites (Figure 4-5), *Renalcis*, etc.

The number of foraminiferans species decreased from the 45th to 55th layers. *Irregularina* sp. (Fig. 2-19, 2-20) only continues to the 55th layer, while *Earlandia* sp. (Fig. 3-3, 3-4) only extends to the 45th layer. The other 10 species all crossed the 55th layer, and *Nanicella* continues to the 55th layer.

Layers 56-63: with foraminiferans, and some brachiopods, ostracods, *Renalcis* (Fig. 4-6, 4-9), *Paraepiphyton* (Fig. 4-8), etc.

5 Foraminiferan assemblages in the Zhongnan section

According to the chronological distribution in the Zhongnan section, the foraminiferans are divided four assemblages (Fig. 5). The first assemblage in 24-27 layers is dominated by the elements of Parathuramminidae; the second assemblage in 28-43layers dominated by the elements of Nodosinellidae; the third assemblage in 44-58 layers dominated by the elements of Parathuramminidae and Caligellidae, and the fourth assemblage in 59-63 layers dominated by the elements of Parathuramminidae, with a monotonous composition and a small number of species.

Table 1 Abundance of foraminiferans in the Zhongnan section

Sample number	species	numbers	slide(piece)	Abundance (n/cm^2)
32	9	43	2	0.61
33	6	26	1	0.74
33-2	5	38	2	0.54
37	5	39	2	0.56
39	3	4	1	0.11
40A	8	28	1	0.80
40B	7	48	2	0.69
41	7	46	1	1.31
45	10	67	2	0.96
46	6	16	1	0.46
48	5	21	2	0.30
50	6	21	1	0.60
54	4	8	1	0.23
57	9	53	2	0.76
59	13	68	1	1.94
62	13	50	2	0.71
64	11	78	2	1.11
65	8	25	2	0.36
67	14	48	1	1.37
69	14	54	2	0.77
71	6	11	2	0.16

Sample number	species	numbers	Thin sections	Abundance (n/cm^2)
72	10	105	2	1.50
75	5	9	1	0.26
77	6	14	2	0.20
78	8	11	1	0.31
78A	11	25	3	0.24
79A	5	15	2	0.21
79B	5	10	2	0.14
79C	6	9	2	0.13
79D	12	40	2	0.57
79E	6	14	2	0.20
79F	13	48	1	1.37
79G	10	27	2	0.39
79H	12	39	2	0.56
79I	6	15	2	0.21
82	11	21	1	0.60
83	8	38	1	1.09
85	5	7	1	0.20
87	12	45	1	0.129
90	14	35	1	0.10
91	5	17	1	0.49
92A	6	8	1	0.23
92B	10	24	1	0.69
93	8	16	2	0.23
94A	4	5	1	0.14
94B	5	12	1	0.34
95	8	34	2	0.49
95-1	4	6	1	0.17
95-2	7	21	1	0.60
97	4	6	1	0.17
98-1	2	6	1	0.17
98-2	7	14	2	0.20
102	2	4	1	0.11
104	5	21	1	0.60
105	3	16	2	0.23
105-2	7	19	1	0.54
105-3	4	19	1	0.54
106	1	1	1	0.30
107	2	6	1	0.17
108	4	4	1	0.11
108+	1	3	1	0.90

Sample number	species	numbers	Thin sections	Abundance (n/cm^2)
109-1	4	11	1	0.31
109-2	3	4	1	0.11
109-3	3	5	1	0.14
109-4	2	2	1	0.6
109-5	2	4	1	0.11
109-6	1	1	1	0.30
109-7	0	0	0	0
109-8	2	2	1	0.60
109+	2	5	1	0.14
113	0	0	0	0
114	7	54	1	1.54
115	5	21	1	0.60
116	5	13	1	0.37
117	1	1	1	0.30
118	4	8	1	0.23
119	3	3	1	0.90
120	2	3	1	0.90
121	5	7	1	0.20
122	7	32	1	0.91
123	7	17	1	0.49
124	3	4	1	0.11
125	9	45	1	1.29
126	8	91	1	2.60
127	9	66	1	1.89
127+	2	5	1	0.14
128	4	11	1	0.31
129	0	0	0	0
130	2	6	1	0.17
131	3	5	1	0.14

6 Abundance of foraminiferans

Abundance of species refers to the number of individuals of a given species per area. In this paper, the total number of foraminiferans in each thin section was counted individually, and the number of individuals of all species in per area of a thin section was calculated, to represent the abundance of the foraminiferan. The statistical results are shown in Table 1, and an abundance curve has been drew (Figure 5).

7 Horizon of the F-F even at the Zhongnan section

The positions of the F-F event in the Devonian sections around the world were determined according conodont zones and carbon isotope curve. The position of the horizon of the F-F event in the Zhongnan section was also determined by conodonts and carbon isotope curve. The conodont data of the Zhongnan section will be published separately, and are briefly described here. Three conodont zones have been identified near the Devonian F-F boundary: the *Palmatolepis rhenana* zone, the *P. linguiformis* zone and the *P. subperlobata* zone (Fig. 5). The *P. rhenana* zone is below the 53rd layer, with the first appearance of *P. rhenana* as the bottom of this zone. The conodonts in this zone include *P. hassi*, *P. subrecta* and *P. g. gigas*. The *P. linguiformis* zone is between 54-55 layers, with the first appearance of *P. linguiformis* as its bottom. The common associated species include *P. ederi*, *P. g. paragigas* and *P. juntianensis*. The *P. subperlobata* zone occurs in the 56th layer and is marked by the first appearance of *P. subperlobata (*Fig. 4-7). The associated species include *P. ultima*. Based on the succession characteristics of the conodont fauna near the F-F event horizon, Klapper *et al*. proposed that the beginning of the Famenian be defined by the abundant occurrence of *Palmatolepis ultima* and the first appearance of *P. subperlobata* (Klapper et al., 2004; Klapper, 2007a, 2007b) . Therefore, in this paper the bottom of the 56th layer, that is, the first appearance of Palmatolepis subperlobata, is considered the F-F event horizon.

8 Extinction pattern in foraminiferans across the F-F event horizon on in the Zhongnan section

8.1 The effect on the genus and species composition of foraminifera

The F-F events, also known as Kellwasser events, include the Upper and Lower Kellwasser events (Fig.6) (Buggisch, 1991; Gradstein et al., 2012). The Lower Kellwasser event (LKW) occurred in the middle of the *Palmatolepis rhenana* zone, corresponding to a positive change in carbon isotope up to 4‰. The Upper Kellwasser event (UKW) occurred in the *Palmatolepis linguiformis* zone and corresponds to the peak of a positive change in carbon isotope up to 4‰.

Internationally, the Kellwasser events occurred with two layers of black shale (Fig. 6), where 80% of marine species became extinct. In the event horizon, reef-building organisms virtually all disappeared; coral drastically reduced to just two or three genera; stromatoporoid numbers plummeted; and three orders of brachiopods and Tentaculites became extinct. After the F-F events, sea levels generally retreated, evaporite deposits became widespread, and glacial deposits appeared in South America (Walliser, 1996; Flügel, 2002; Blieck, 2007; Racki, 2005, 2020).

In the Zhongnan section, stromatoporoids, corals and red algae are present in the 44th layer and below; from the 45th layer upwards, stromatoporoids, corals and red algae disappeared, and cyanobacteria appeared, and the *Palmatolepis rhenana* zone occurs below the 53th layer (Fig. 5). So, the Lower Kellwasser event horizon in the Zhongnan section lies in the 45-51 layers. During the Lower Kellwasser Event horizon, two foraminiferal species became disappeared: *Earlandia* sp. and *Nodosinella* sp. (Fig. 5). Before the extinction, the number of foraminiferal species was 14, the extinction rate is 7%.

The *Palmatolepis linguiformis* zone lies in the 54-55 layers (Fig. 5). According to the criteria of conodont zone, the upper Kellwasser event horizon should be in the 54-55 layers. During the Upper Kellwasser event, the two foraminifer species, *Irregularina* sp. and *Nanicella* sp., became disappeared (Fig. 5). Before the extinction, there were 12 foraminiferal species. Thus, the extinction rate is 16%. During Earth's history, there have been numerous mass extinctions triggered by global catastrophes.

According to the definition (Jablonski, 1986), a mass extinction event is recognized if more than 75% of species become extinct.

As seen in Fig.5, the 28th layer contains 18 species of foraminiferans. In the 28-44 layers below the Kellwasser event horizon, four foraminiferal species became disappeared, the extinction rate is 22%. In both the Lower and Upper Kellwasser event horizons, the extinction rates of foraminiferan species are lower than the extinction rate below the Kellwasser event horizons. The no mass extinction occurred in the Kellwasser Event horizons in Zhongnan section.

8.2 Change in foraminiferal abundance in the F-F event horizons

According to Fig.5, the foraminiferal abundance curve began to decline from the 38th layer, reaching its lowest point in the Lower Kellwasser event horizon (45-51 layers). There was a marked increase in foraminiferal abundance in the lower part of the Upper Kellwasser event horizon, and it declined to the lowest level in the upper part of the Upper Kellwasser event horizon. Overall, in the Upper and Lower Kellwasser event horizons, foraminiferal abundance is at its lowest in this section. The lithology in the Lower Kellwasser event horizon differ markedly from those above and below, is mainly mud limestone, indicating low hydrodynamic energy, deep water. The lithology at the Upper Kellwasser event horizon is grainstone, in which the foraminiferal abundance is generally very low.

The fact that, although the lithology at the Upper and Lower Kellwasser event horizons is different, but the abundance of foraminiferans is relatively low, indicates that the low abundance of foraminiferans here is not solely due to the water dynamic energy or water depth of the environment. The environmental change in the Kellwasser event horizons have had a impact on the foraminiferal abundance. As mentioned above, there is no obvious change in foraminiferan diversity in the lower and upper Kellwasser event horizons, it can be concluded that the abundance of foraminiferans was affected in the Lower and Upper Kellwasser event horizons, but the species diversity of the foraminiferans has not been affected in the Kellwasser event .

9 Conclusions

We studied the foraminiferan fossils from the Late Devonian F-F boundary section at Zhongnan, Guilin, Guangxi province, China, and reached the four conclusions:

13 genus 19 species (8 undetermined species) of foraminiferans were identified from the section: *Cribrosphaeroides parasimplex*, *Cribrosphaeroides robusta*, *Archaesphaera giganta*, *Archaesphaera crassa*, *Parathurammina horrida*, *Parathurammina* sp., *Paracaligella antropovi*, *Paracaligella* sp., *Bisphaera* sp., *Irregularina* sp., *Earlandia* sp., *Eovolutina elementa*, *Nanicella* sp., *Septabrunsiina donica*, *Paratikhinella cannula*, *Tikhinella* cf. *measpis*, *Tikhinella* sp., *Nodosinella* cf. *evlanensis*, *Nodosinella* sp.

Four foraminiferan assemblages were recognized: the first one dominated by the elements of Parathuramminidae; the second one dominated by the elements of Nodosinellidae; the third one dominated by the elements of Parathuramminidae and Caligellidae, and the fourth one dominated by the elements of Parathuramminidae, with a monotonous composition and a small number of species.

The extinction rate of foraminiferan species in the F-F event horizons is only 7-16% in this section, while the extinction rate below the F-F event horizons is 22%, which indicates that foraminiferans were not affected in the F-F event horizons, but, the abundance of the foraminiferans decreased significantly.

10 Acknowledgements

This research was supported by the key Program of the National Natural Science Foundation of China through grant 42330203. We are much indebted to professor Daizhao Chen, Saiye Zhang, Huihong Liao from the Institute of Geology and Geophysics, Chinese Academy of Sciences for their invaluable help and assistance during the fieldwork. Thanks also go to Ying Tian and Xiaoyu Jia for their help in daily work.

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Published on: 25 May, 2026